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Review

A comprehensive framework for strategic energy planning based on Danish and international insights

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ABSTRACT

The transition towards renewable energy systems is guided by different energy planning approaches around the world. The strategic energy planning approach has gained increasing attention during the last decade and it is the approach chosen for the Danish energy transition. Challenges are found in Danish strategic energy planning approach today. This paper examines how to improve the implementation of strategic energy planning in Denmark. Through identification of challenges in the Danish approach and a review of international literature on strategic energy planning, it is possible to identify key elements that can be integrated into the Danish definition. Furthermore, a theoretical framework is developed that can be used to analyse strategic energy planning in practice.

1. Introduction

Climate change is a worldwide challenge and is highly connected to the consumption of fossil energy sources. Within this, the production of energy and transportation are the largest emitters of CO_2 and other greenhouse gases. It is therefore necessary to identify new ways of producing and consuming energy using renewable energy sources. Many countries have made national energy goals to limit and prevent climate changes and numerous different energy planning approaches have been introduced around the world to fulfil these goals. To mention some: Centralised Energy Planning [1], Decentralised Energy Planning [1], Integrated Energy Planning [2] and Community Energy Planning [3], Strategic Energy Planning [4–7].

Denmark has the national goal of a complete phase out of fossil fuels in all sectors of the energy system by 2050 [8,9]. This means that we are in the middle of a major transition of the energy system from a centralised fossil-based energy system to a more decentralised system based on renewable energy resources. At the same time, this may also mean moving away from sector-based approaches to more integrated energy systems based on cross-sector solutions and synergies. One possible path of development in this transition is that some new parts of the energy supply, conversion and integration infrastructure are constructed closer to the consumers, in the form of e.g. wind turbines, combined heat and power plants (CHP), district heating, electric vehicle charging stations, biofuel plants, electrolysers etc.[1] [5,10,11]. Yet, so far, there has been a tendency in energy planning to treat the different sectors of the energy system as mostly separate from each other. Examples of this can be found in local energy planning documents in the

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[1] It is not possible to predict exactly "how much" decentralization will happen or is necessary to achieve 100% renewable energy. Factors, such as economies of scale, spatial constraints and social acceptance will play a role in finding an "optimal" level of decentralization. It is also very likely that without a change in energy policy, some sectors, such as electricity production, may become more centralised again: e.g. in the form of large offshore and onshore wind farms and large electricity transmission infrastructures. Looking only at the electricity supply, 100% renewable energy may be achieved rather quickly in this way. According to the smart energy systems perspective, however, such central infrastructures are not sufficient in order to achieve a completely fossil-fuel-free energy system. They may even be in competition with cross-sector solutions that utilize excess electricity to replace fossil fuels in the heating, transport and gas sectors [112]. While there seems to be no doubt that electrification of the transport and heating sectors also can happen in a centralised energy system – and thus, a complete phase out of fossil fuels, too – the smart energy system approach suggests that this may not be the most cost-effective solution when compared to solutions that utilize cross-sector integration locally and on a smaller scale. This is mainly because under the current electricity market constructions central solutions, such as increased used of electricity transmission across countries, will lead to smoother prices curves, which reduces the incentives for electrification technologies, such as heat pumps and electric vehicles – and this even though these technologies may be needed anyway to replace fossil fuels in heating and transport. Thus, the smart energy system concept suggests using the flexibility of these technologies to better integrate renewable energy and energy sectors, before the need for more transmission line is investigated [128].

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municipalities, where energy sectors and technologies have often been regarded individually with little focus on the synergies between them [12–14]. In the Danish case, an increasing amount of research suggests that in order to cost-effectively achieve a 100% renewable energy system, a much stronger integration of the energy system through cross-sector solutions is necessary. The term Smart Energy System has been developed [15,16] by Lund et al. to describe such a fully integrated renewable energy system:

> *'Smart energy systems are defined as an approach in which smart electricity, thermal, and gas are combined and coordinated to identify synergies between them in order to achieve an optimal solution for each individual sector as well as for the overall energy system'.* [17].

According to the smart energy systems perspective, it is necessary to develop the energy system as a coherent smart energy system that integrates the different sectors (electricity, thermal, gas grid) [16–20]. The combined integration of all energy sectors makes it possible to exploit the synergies between sectors, which can lead to a more efficient and flexible energy system – as opposed to trying to resolve imbalances within the electricity sector only, for instance. The development of such an energy system is more than just a technical matter. It is highly connected to social, environmental and economic aspects, making the transition of the energy system a complex task with necessary coordination between institutional levels and different sectors. Therefore, there is a strong need for energy planning practices that can embrace all these elements [21,22]. Furthermore, energy planning should be able to embrace local energy system challenges, within the smart energy system perspective.

The Danish government has introduced strategic energy planning as the planning practice recommended for municipalities in the transition to a 100% renewable energy system [7,23,24]. Even though the Danish government includes all energy sectors in the transition of the energy system, they do not fully address the importance of harnessing the synergies of cross-sector integration. This is e.g. seen through the government's approach to address the individual sectors and energy resources without any mentioning of synergy effects or the prioritization in the combination of the energy technologies [7]. This indicates a necessity to continuously develop and concretise the concept. In this paper the lack of connection between strategic energy planning and smart energy systems is seen as a lack in the Danish strategic energy planning approach. This paper's starting point is that, smart energy systems should be integrated into the definition as a core approach for strategic energy planning. The smart energy system approach includes 100% renewable energy systems analysis and design as well as socio-economic feasibility studies. By combining technical and economical energy system analysis in this way, an increasing number of studies now indicates that this approach can identify socio-economically optimal 100% renewable energy systems [20,25,26].

The Danish government introduced the concept of Strategic Energy Planning in Denmark in 2012 through the Energy Agreement [27] and based on the recommendations of a workgroup on strategic energy planning from 2010 [24]. However, the development and implementation of the strategic energy planning approach in its current form has only been integrated slowly into Danish energy planning, despite the central government's encouragement. It is therefore interesting to investigate the research question: **How can the implementation of strategic energy planning be successfully improved?**

To answer this research question two sub-questions are defined to structure the analysis in the paper:

- Which challenges are found in Danish strategic energy planning?
- How can international academic literature on strategic energy planning shed more light on the Danish and other countries' challenges in relation to strategic energy planning?

1.1. Structure of the paper

Section 2 describes the methodology used in the paper. Section 3 describes strategic energy planning in the context of Denmark and the challenges found in connection to it. In section 4, international academic literature on strategic energy planning is examined to identify how the international use of strategic energy planning can help to shed light on the Danish challenges. In section 5, a discussion of the findings is presented and an analytical framework for future research and practice in strategic energy planning. Furthermore, section 5 also points out some areas for further analyses. Lastly, section 6 concludes the paper.

2. Methodology

This paper is built around two separate literature reviews both conducted within the scientific database ScienceDirect. Examinations in the paper are likewise divided into two parts based on the three objectives.

The first part is based on a literature search on non-academic and academic publications concerning strategic energy planning and climate action plans in a Danish context. The search for academic papers resulted in four papers, where one is a direct case study of municipal strategic energy plans [28] and the other three are concerned with targets, actions, motives and practical possibilities in strategic energy planning at the local level [5,6,29]. Furthermore, eight non-academic documents concerning Danish strategic energy planning are considered in order to obtain an overview of the development of Danish strategic energy planning since around 2010 [7,19,24,27,30–33].

In the second part of the article, we examine how strategic energy planning is generally used and defined in the academic literature: a review of scientific publications mentioning the term "*Strategic Energy Planning*" is conducted. A search in the scientific databases ScienceDirect and Scopus for academic papers mentioning "*Strategic Energy Planning*" in the title or somewhere in the paper resulted in 189 items, of which 125 documents could be located and analysed. This means that 64 papers were not included in the study; consequences of this may be that some aspects of strategic energy planning have been left out. The review of the identified 125 papers is structured in a spreadsheet, where each paper is characterised by title, year, journal, case country/area and keywords in relation to strategic energy planning, forming the basis for the analysis. In the paper, the analysis of the international literature is structured so that each paper was analysed to identify keywords in relation in strategic energy planning, tools/methods for conducting strategic energy planning, levels that strategic energy planning is conducted on and lastly, stakeholders mentioned in relation to strategic energy planning.

To identify differences and similarities between strategic energy planning (in its various definitions) and other energy planning approaches that appear in the academic literature, an overall database search was made. For this purpose, a focused search for review papers on ScienceDirect, both, "Energy Planning" and "Review" included in the title was made. This approach was chosen because a classification of all scientific publications under the search terms "energy planning" is beyond the scope of this paper.[2] The search on ScienceDirect resulted in eight review papers. These papers are used as the basis for the identification of different energy planning approaches used today.

3. Strategic energy planning in Denmark

It is widely recognised that municipalities should play an important role in climate management [5,6,29,34–37]. A focus on climate

[2] In ScienceDirect and Scopus, the keywords "energy planning" yield 556,554 and 63,848 results, respectively.

management in municipalities was especially raised in 1992 under the United Nations Conference on Environment and Development, where an agreement on the plan of action "Agenda 21" [38] was made. In Denmark, Agenda 21 was included in the Planning Act in Chapter 6a "Lokal Agenda 21", stating that the city councils are obligated to publish a report with their strategy for sustainable development in the municipality every fourth year. Energy is not mentioned in the Planning Act as part of a strategy for sustainable development, but environmental impact is a central element [32]. Reductions of environmental impacts are partly measured in terms of CO_2 emissions, making a direct connection to the use of fossil resources in energy production. Therefore, climate action plans are important for the development of energy planning at a municipal level, since many Danish municipalities have combined energy and climate strategies. In 2010, strategic energy planning was introduced as a desired planning approach for local energy planning in Danish municipalities. In 2010 the Danish Energy Agency introduced a definition of strategic energy planning:

> *'The strategic energy plan is a planning tool that gives municipalities the opportunity to plan local energy conditions for a more flexible and energy efficient energy system, in preparation for the potential transition to a more renewable energy, and where energy savings are exploited in a way that is socially most energy effective'* [30], p.7 [translated from Danish]

> *'… Strategic energy planning shall secure a future energy system that is both energy efficient and flexible. Strategic energy planning includes all possible elements of municipalities' energy plans, and coordination with municipal plans, security of supply strategies and climate strategies. The municipalities should conduct energy planning to create an optimal interplay between the energy demands and energy supplies (heating, cooling and electricity) in such a way that the energy resources are optimally used. Energy planning encompasses the whole energy chain and differs thereby from heat planning, which solely looks at the choice of heat supply'.* [30], p.7 [Translated from Danish]

To support the development of strategic energy planning in the municipalities, the Danish Energy Agency published two guidelines for the municipalities to use in the development of strategic energy plans. The first, published in 2012, was a guideline on mapping and data gathering [33], and the second guideline on analyses of system changes and scenario analyses was published in 2013 [31]. One thing that the Danish Energy Agency is very clear about is that the guidelines should only be seen as guiding principles for the municipalities, and it is only voluntary for municipalities to make use of the methods described in the guidelines.

From the Danish government's definition of strategic energy planning, three main elements can be identified: municipal task, development of plans and the inclusion of the whole energy chain. With this the Danish government says that strategic energy planning is a municipal responsibility, even though they do not provide any permanent funding for the municipalities to fulfil this responsibility. This means that the municipalities themselves should budget for strategic energy planning within their municipal budgets.

A literature search for academic papers on strategic energy planning in a Danish context reveals a primary focus on energy planning conducted at the municipal level, which is in line with the directions the Danish government stated in the Energy Agreement of March 2012 [27]. Another finding is that energy planning and climate planning cannot be unrelated, since municipal energy planning originates from climate planning. Therefore, studies in both strategic energy planning and climate action plans are considered in this paper. A few studies within municipal climate action plans and energy plans have been identified and in these papers the targets in the plans have been examined [5,6,29,37]. However, the examination of both climate action plans and energy plans means that it can be difficult to see which type of plans have been examined in different studies. Damsø et al. used the terms energy plans and climate plans interchangeably based on the argumentation that this is the way it is used in reality in the municipalities [6].

Both Sperling et al. [5], Damsø et al. [6] and Hoff and Strobel [29] examined the details of existing municipal energy plans and the extent to which these plans live up to the national energy strategy, which has a goal of reaching 100% renewable energy. Sperling et al. and Hoff and Strobel concluded that while there is a willingness in the municipalities to conduct energy planning, at the same time there is a need for improved coordination from the national level of the energy planning activities in the municipalities [5,29]. All studies argued that there is a large variety in the targets and quality of the local energy plans and that there is a need for local strategic energy planning, customising local actions within the framework of the national energy policy and targets [5,6,29]. This is most likely due to the fact that it is a voluntary task for municipalities in Denmark to conduct strategic energy planning and develop strategic energy plans [29]. Furthermore, no permanent funds are allocated to the municipalities for this purpose [7,29]. This means that it is up to the individual city councils in the municipality to decide the priority of energy in the budget in relation to other areas, such as elderly care, education, childcare, road infrastructure, etc. [5]. In relation to this, Hoff and Strobel found a large difference in ambitions in the plans depending on which personnel are responsible for the plan. If a certain unit in the organisation or a leading civil servant is responsible, the plans more ambitious than when they are in situations where the responsibility becomes an added assignment on top of other tasks [29]. Another finding is that local politicians can limit the development of the strategic energy plans, due to political strategies that will benefit the reputation of the politicians. The politicians attach importance to e.g. visible and short-term projects and projects that show that climate change projects are economically beneficial [29].

The content of the strategic energy plans does, in most municipalities, primarily cover the organisations' own activities and not citizens' activities, meaning that a large potential, especially within energy savings and transportation, is not covered [29]. Hoff and Strobel point out a missing link in the communication between the municipalities and citizens and businesses that should be improved in order to benefit from the resources found in civil society [29].

Based on the work from Sperling et al. Damsø et al., Hoff and Strobel and the Danish Energy Agency's definition of strategic energy planning, an understanding of how Danish strategic energy planning is understood today is depicted in Fig. 1.

The academic literature indicates that the current political framework around strategic energy planning is still not fully defined and developed in the Danish context and point out that there are some weaknesses in the Danish model. Thellufsen et al. [20] point out some of the current challenges strategic energy planning faces. Firstly, national plans for a 100% renewable national energy system are developed, but they do not include local implementation strategies. Secondly, municipalities are increasingly looking into local energy targets, and while this is not necessarily a problem, they do not always consider the national renewable energy targets [20]. The problem with this is that the combined municipal energy targets might not align with the national targets and thus, this development can hinder national 100% renewable energy systems. However, Thellufsen et al. also point out the importance of local actions in finding the right balance between national and local energy planning [20]. Furthermore, it can be argued that the national guidelines for Danish strategic energy planning [7,31,33], only focus on a limited part of strategic energy planning, namely data gathering and mapping of resources as well as suggestions for specific analyses that can be made in the strategic energy planning process. The guidelines provide a first overview of possible actions and different roles that municipalities can take in the energy planning process. The broad variety of suggested actions in the guidelines leaves room for the municipalities to choose the actions that best fit into their specific context and local budget. However, this also leaves room for

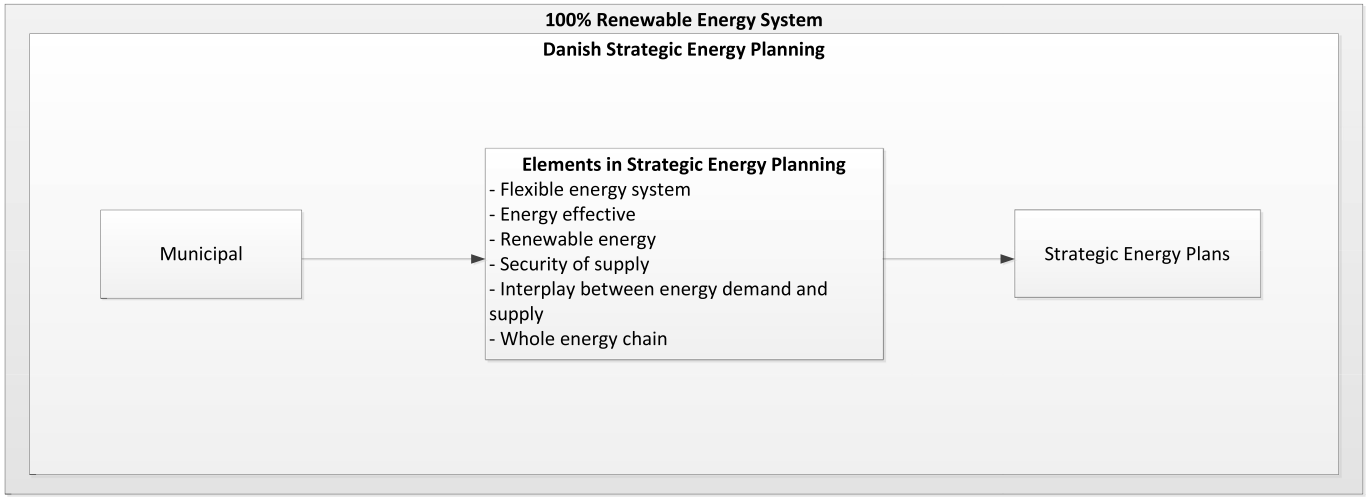

Fig. 1. Danish strategic energy planning. Picture of Danish strategic energy planning approach based on the definition given by the Danish Energy Agency and the work carried out by Sperling et al. [5], Damsø et al. [6] and Hoff and Strobel [29]. The municipalities are (voluntarily) responsible for developing strategic energy plans, which can include some or all of the elements seen in the middle box in the figure.

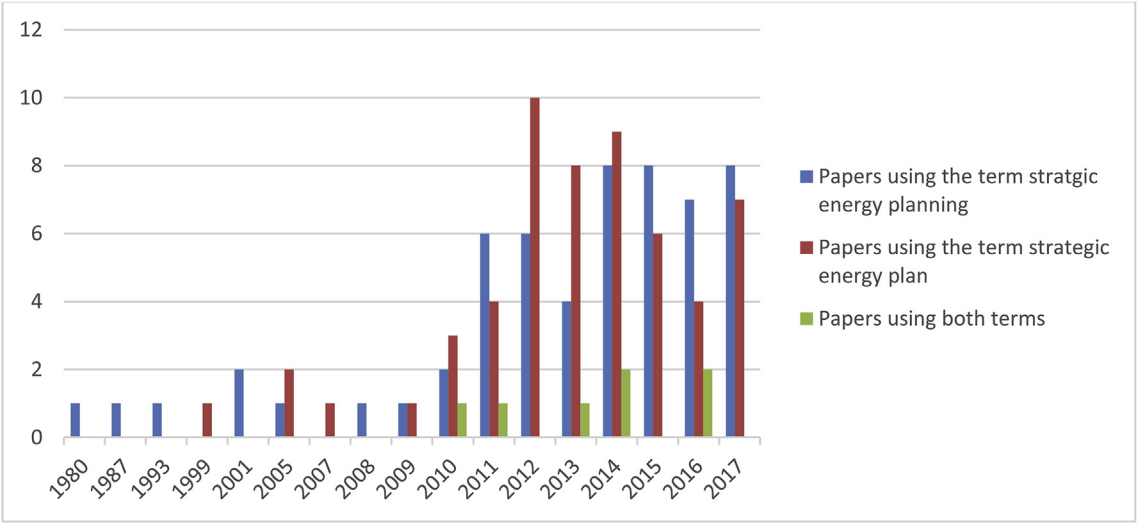

Fig. 2. Number of papers using the terms strategic energy planning or strategic energy plan or both terms.

potential inconsistencies between the strategic energy plans, and may cause some municipalities to fall behind in the green transition of the energy system. The national guidelines, thus, focus mainly on some issues relevant for *municipal* strategic energy planning, and leave out other elements of strategic energy planning linked to e.g. local-national coordination of strategic energy planning and involvement of important actors outside the jurisdiction of the municipalities (TSOs, gas network operators, regions and other supra-municipal entities etc.).

To sum up the challenges found in literature regarding Danish strategic energy planning the following point are highlighted:

- No funds are allocated to strategic energy planning and at the same time, it is a voluntary task, meaning that each municipality decides whether or not to allocate funds for local strategic energy planning.
- High divergence in the targets and quality in the municipal strategic energy plans, which can lead to sub-optimisation and potential non-fulfilment of and misalignment with national goals.
- Strategic Energy Planning in its current form does not yet successfully address short-term optimisation at the expense of long-term optimisation in e.g. a smart energy system perspective. This is, for instance, evident in some (local) politicians' or decision makers' promotion of sub-optimal projects, which create immediate visibility with the potential purpose of political popularity.
- The Danish strategic energy planning approach does not include local implementation strategies.
- Municipalities focus on local energy targets and not national energy targets (can lead to sub-optimisation).
- Lack of clearly defined and concrete framework conditions and guidelines for the complete energy system (smart energy system), which can lead to sub-optimisation and/or lack of local political decision making.

These are challenges identified in Danish strategic energy planning; however, it is not clear if these are general challenges in strategic energy planning from an international perspective. In the following section, the available academic literature on strategic energy planning is reviewed in order to compare possible challenges mentioned therein with the Danish case, and to investigate whether the general literature can contribute to overcoming some of the challenges identified in the Danish approach.

4. Strategic energy planning internationally

The use of the term strategic energy planning has developed over

Table 1
Keywords, tools/methods, institutional levels and stakeholders identified throughout the literature in relation to strategic energy planning.

Keywords	Tools/methods	Levels	Stakeholders
- Short-term [4,6,47,86,87]	- GIS-based analyses [113]	- Cities (urban planning) [44,62,96–99]	- Municipalities [5,20,35,43,99,116,117]
- Mid-term [4]	- Scenario analyses [15,17,21,112]	- Municipalities (local) [5,35,109,115]	- Local Utilities [43]
- Long-term [4,21,39,41,44,47,48,83,86–98]	- SWOT analyses [21]	- Regional [99,115]	- Citizens [35,91,92,96,98,99]
- Holistic [40,93,96,98,99]	- System Dynamic modelling [114]	- Central (national) [5,109,115]	- State/Government [5,42,83,89,95,118–120]
- Sustainable [4,21,35,44,48,97,100]	- Optimisation models [86]		
- Strategy document (strategic energy plan) [35,52–56,58,59,62–64,66–69,72,73,76,78,80–82,88,90,98,101–108]			
- Reduce end-use energy demand [96]			
- Community goals [48]			
- Renewable energy sources [109]			
- Stakeholder involvement [4,21,35,48,100,110]			
- Efficiency [86,97]			
- Improving welfare [4]			
- Reliability [86]			
- Integrated system thinking [109]			
- Energy Supply and Demand [21,88]			
- Resiliency and security of energy infrastructures [86]			
- Cost structure of energy production [111]			
- comprehensive energy system [40]			
- Land-use [96]			
- Smart Energy Systems [15,17,109,112]			

time. Fig. 2 shows how the number of studies using the term has increased over time. Strategic Energy Planning was mentioned for the first time in 1980 by W. Häfele in relation to formulating a long-term global energy supply strategy [39]. From 1980 up to 2010, strategic energy planning is only mentioned in a few papers, but from 2010 a large increase in the number can be seen in Fig. 2. This is around the same time that the concept of strategic energy planning occurs for the first time on the governmental level in Denmark [24] putting a focus on Danish strategic energy planning, which corresponds well with 2011 being the year that academic papers with Danish cases start to appear [5,6,20,40–43].

The use of the term strategic energy planning can be divided into two main groups: 1) strategic energy planning as a concept (as a word without any further exploration or as a word related to specific elements, institutional levels or methods) 2) strategic energy plan as a specific plan for an area such as a country or a municipality. Fig. 2 illustrates the extent to which these terms have been used historically in the literature; only a few studies use the terms strategic energy planning and strategic energy plan together [5,40,44–48].

The term strategic energy plan is highly connected to specific case studies mentioning a specific strategic energy plan for a county or smaller area in connection to implementing a technology in the energy system [49–57]. Since most papers only mention strategic energy planning and strategic energy plans as a concept or product it is hard to identify what they precisely put into the concept. To reach an indication of how different authors define the concept, the different papers have been analysed to identify which sectors in the energy system are covered in the different studies. The Danish definition of strategic energy planning embraces all sectors within the energy system. However, the literature review reveals differences in the use of the concept: only 18 of the total 125 examined papers mention the complete energy system in relation to strategic energy planning, 33 papers focus only on electricity, 10 papers mention more than one sector but not all. The most striking finding is that it was not clearly possible to identify how 64 of the papers define the energy system in relation to their use of strategic energy planning.

Furthermore, an observation can be made that Japan is the country represented in a majority of the case studies [49,53–55,58–83]. These case studies mainly focus on the Japanese Strategic Energy Plan after the Fukushima disaster in 2011, which seems to have received broad attention to the Japanese energy supply and the political choice of integration of more renewable energy sources in the energy system to replace nuclear power plants. This is an example of how historical events can lead to a shift in governments and cultures, leading to support and acceptance of new approaches in the development of the energy system [84]. Another example are the oil crises in the early 1970s, which led to the first Danish national energy policy in 1976, which had a focus on decreasing the dependency on oil in the Danish energy supply [85].

Studying the development and use of strategic energy planning in the academic literature also gives an opportunity to identify different key aspects used in relation to the concept and from that develop a general understanding of strategic energy planning and to identify aspects left out in the Danish understanding.

Considering how the two terms are used in different studies, it becomes clear that strategic energy planning is typically used in relation to different energy production technologies. Focus is on the technical implementation of the technology and the relation to the surrounding energy system and society is often missing. Only a few papers comment directly on what strategic energy planning is and only one of the reviewed papers presents a definition of strategic energy planning. Across the different studies, a number of keywords are identified in relation to strategic energy planning and the understanding of what it is and how it can be used. Furthermore, some tools used to conduct strategic energy planning are identified together with specific stakeholders that should be included when conducting strategic energy planning.

Table 1 summarises the keywords, tools and methods, different levels and stakeholders mentioned in relation to strategic energy planning in the literature. These categories are chosen to illustrate how strategic energy planning is used. The keywords provide a picture of the elements included when strategic energy planning is used. Tools/methods are chosen to obtain an understanding of how strategic energy planning is conducted. Finally, levels and stakeholders are chosen to illustrate where strategic energy planning is conducted and who is involved. The review of the literature related to strategic energy planning indicates that different studies use the term strategic energy planning in

Table 2
Identified understandings and definitions of Energy Planning.

Energy Planning approach	Definition/understandings	Sources
Danish Strategic Energy Planning	*"The strategic energy plan is a planning tool that gives municipalities opportunity to plan the local energy conditions for a mere flexible and energy effective energy system in preparation for that the potential for the transition to more renewable energy and energy savings is exploited in a way that is most energy effective for the society"* [30], p.7 [translated from Danish] *" … Strategic energy planning shall secure a future energy system that is both energy effective and flexible. Strategic energy planning includes most possible elements in the municipalities' energy plans and the energy planning is coordinated with municipal plans, security of supply strategies and climate strategies.* *The municipalities should conduct energy planning in order to obtain an optimal interplay between the energy demand and energy supply (heating, cooling and electricity) in such a way, that the energy resources are used most optimally. The energy planning encompasses the whole energy chain and differs thereby from the heat planning, which solely looks at the choice of heat supply …"* [30],p.7 [Translated from Danish]	[30]
Strategic Energy Planning	*"UN (2002) defines SEPM* [strategic energy planning and management] *as 'an approach by which Governments (and stakeholders) take a long-term view of trends in natural resource use and environmental and social quality (described as the 'vision'), identify the changes necessary to bring these trends within sustainable limits and to establish a management framework to encourage key groups in society to achieve these goals'"* [4]p.607.	[4]
Integrated Energy Planning	*"Regional (sub-national) integrated energy planning is an approach to find environmentally friendly, institutionally sound, social acceptable and cost-effective solutions of the best mix of energy supply and demand options for a defined area to support long-term regional sustainable development. It is a transparent and participatory planning process, an opportunity for planners to present complex, uncertain issues in a structured, holistic and transparent way, for interested parties to review, understand and support the planning decisions"* [2],p.290	[2]
Community Energy Planning	*"CEP[Community energy planning] includes not only the community energy system and facility design but also all energy-related issues in a community, such as setting an energy consumption target, selecting energy resources, and energy conversion technologies evaluation."* [3],p.1336	[3]
Energy Planning	*"Energy planning can be defined as a roadmap for meeting the energy needs of a nation and is accomplished by considering multiple factors such as technology, economy, environment, and the society that impact the national energy issues"* [21],p. 686	[21]
Energy Planning	*"Energy planning determines the optimum combination of energy sources to satisfy a given demand. This is done by taking into consideration the multi-criteria for decision making, which are, qualitative (economic and technical criterion) and qualitative (environmental impact and social criterion)."* [21],p.687	[21,122]
Energy Planning	*"… the basis for energy planning is to satisfy the forecasted energy demand over a given time period by taking into account political, social and environmental considerations, as well as historical data collected for previous energy plans for the location under consideration."* [21],p.687	[21,123]
Energy Planning	*"The energy-planning endeavor involves finding a set of sources and conversion devices so as to meet the energy requirements/demand of all tasks in an optimal manner."* [1],p.735	[1,21]

different ways and connect it with different keywords and elements, making it difficult to find one common understanding of strategic energy planning, even though some similarities are identified.

As mentioned above, only one paper uses a definition of strategic energy planning. Moghaddam et al. [4] use the United Nation's definition from 2002:

> *'UN (2002) defines SEPM* [strategic energy planning and management] *as "an approach by which Governments (and stakeholders) take a long-term view of trends in natural resource use and environmental and social quality (described as the 'vision'), identify the changes necessary to bring these trends within sustainable limits and to establish a management framework to encourage key groups in society to achieve these goals"'* [4] p.607.

When comparing this definition to the definition of strategic energy planning set by the Danish government, the most striking thing is the different focus on the primary stakeholder. The UN mentions central governments as the primary stakeholder in strategic energy planning, while with strategic energy planning in its current Danish definition, some of this responsibility was handed down to the municipalities directly. Furthermore, there is a difference in the elements included in the definitions. The UN mentions environmental and societal aspects as being important in the development of a management framework for reaching energy goals, whereas the Danish Energy Agency has a larger focus on the technical side of the energy system. It can be discussed if a more holistic definition, such as the one made by the UN, should form the basis for the national and local definitions of strategic energy planning. For instance, social issues (such as acceptance and ownership) are also important in the Danish energy system, and should be addressed in energy planning.

To achieve goals set by governments and local authorities, the development of models and scenarios are seen as an important element when decisions about the energy system are made [15,17,21,112]. Adhikari and Manfren [86] highlighted the importance of optimisation techniques and models in the strategic energy planning for obtaining reliability, efficiency and resiliency in the energy infrastructures in the future. They work from a building scale perspective and pointed out the importance of a distributed energy system that provides electricity, heating and cooling [86]. This coincides well with the concept of smart energy systems, where scenario analyses taking the entire energy system, electricity, heating and cooling, gas, industry and transportation sectors into account are seen as an important elements for identifying the optimal solutions, based on different possible future scenarios [15,17,112].

Another observation is that strategic energy planning is mentioned on different levels: Governmental/national, Regional, Municipal, City/urban. Even though, this is the case, most of the studies are concentrated on one level; in particular, the city level is often mentioned throughout the literature on national strategic energy plans [44,62,96–99]. Since strategic energy planning is conducted on different levels, is it important to recognise the link between the different levels and that they cannot be handled as being completely separated. This is because some problems can only be handled on a building scale, such as architecture and implementation of energy efficient applications in buildings, while planning for district heating and combined heat and power plans systems needs attention on a more aggregated level [99,121].

When looking into the term strategic energy planning, strategic energy plans are an important when it comes to setting targets and actions, both on the national and local level. However, Gustafsson et al. pointed out that the effects of conducting such documents has been questioned over time, with reference to local authorities having a limited number of actions they can actually take. Gustafsson et al. give an example: *'Historically, however, the effectiveness of producing such documents has been questioned. For example, many of the factors influencing the energy system lie beyond the reach of local authorities, such as*

implementation of energy efficient measures in households and industry' [35] p.207.

Based on the literature, different elements in the strategic energy planning have been identified in Table 1. The list of elements should not be considered as a definite list but rather as a way to show how different studies focus on different elements in the strategic energy planning depending on the context they are examining. Even though it seems that the term long-term planning is mainly used to describe the strategic element in strategic energy planning, long-term planning is often used in combination with the terms shot-term and mid-term, thus striking a balance between the three.

Strategic energy planning is a complex process which builds on earlier energy planning approaches and it is, as mentioned in the introduction, developed and used in parallel with other forms of energy planning approaches as well. The review of strategic energy planning together with other energy planning approaches results in an identification of different definitions and concepts. These different energy planning definitions and concepts are summarised in Table 2.

A common focus in the definitions and reviews is sustainable development as the main indicator for the decision making in the energy planning process. Moreover, implementation of renewable energy sources is one of the key drivers in the energy planning processes [1–3,21,30,124–127] as well as a long-term perspective in energy planning [1–4,21,125,127]. This is in line with the review made by Prasad et al. [21] where different factors in energy planning processes are addressed, describing energy planning as a multi-faceted process. Their main conclusion regarding energy planning is:

> *"Long-term energy planning is carried out for strategic planning to study the impacts of structural changes, environment and social requirements and new technologies on the energy system. A global, national or regional energy plan must foster sustainable development which implies that in the long-term energy sources must be sufficiently and readily available at reasonable cost to cater for energy needs of the society without having adverse effects socially and environmentally."* [21], p.696

Long-term planning is not directly mentioned in the Danish definition of strategic energy planning, but the phrase "future energy system" is mentioned and this can be read in a way that indicates a long-term focus. Sustainable development is not mentioned in the Danish definition, based on the reviewed literature, which underlines the narrower Danish focus.

Furthermore, there is no consistency to be found when it comes to the levels at which the energy planning approaches should be conducted. Different levels are mentioned in the literature, including the governmental level [99,115], regional level [2,99,115], municipality level [5,30,35,109,115], and community/city level [3,44,62,96–99].

The Danish definition is very clear that strategic energy planning is an assignment for the municipalities. In other definitions and literature using strategic energy planning, other levels (national, regional) are mentioned as the main level. Based on these findings, an argument can be that clearly all levels are important in strategic energy planning, and perhaps, it is a question of finding the right balance between the different levels rather than only focusing on one level in the definition. This is also what Thellufsen indicates as one of the challenges for the Danish energy system today [20].

Based on the findings in the literature review, a development of Fig. 1 (The Danish understanding of strategic energy planning) has been made to show the dynamics of strategic energy planning in general, in Fig. 3. The review of strategic energy planning and the meta review of other energy planning approaches indicate that the Danish strategic energy planning approach is defined relatively narrowly and that it could benefit from a more comprehensive perspective if the approach is to eliminate the challenges identified in section 3. Fig. 3, summarises the findings that could be included into Danish strategic energy planning to broaden the concept and to develop it into an adequate approach for achieving a complete phase out of fossil fuels in all energy sectors. Based on the findings, currently strategic energy planning is mainly regarded as an energy planning approach with the strategic energy plan as the main outcome. The strategic energy plan can include a wide range of elements chosen by the stakeholders developing the plan. There are no definitive rules for what should be included in a strategic energy plan: the involved stakeholders can include any number of elements they find appropriate for their strategic energy plan. Strategic energy plans are developed on different levels, from the national level down to city level. In many cases, the further one moves away from the national level, the more complex the planning processes get, because the implementation of technological solutions becomes more concrete. This means that goals for e.g. wind power deployment and district heating can be set nationally, but placing and putting up wind turbines and district heating includes longer processes and more actor involvement locally. Municipalities and cities possess local knowledge that cannot be obtained at the national level and the coordination between the different levels is therefore extremely important. Taking the example from a municipality level, one will have to develop overall goals for the municipality while considering the overall national and regional goals. At the same time, it is necessary to consider the local communities and cities where the municipal strategic energy plan has to be accepted and implemented. Strategic energy planning can therefore in practice not be conducted from only a top-down or bottom-up perspective, but rather a combination is needed to fulfil the overall goals in a way that considers and respects the local values and possibilities. Another dimension, not elaborated further on in this paper, is the coordination between the different energy sectors, in order to develop a smart energy system.

5. Discussion

When examining strategic energy planning in the Danish context, several challenges are found. The international literature operates with a great variety of definitions, concepts and understandings of strategic energy planning. From this multitude of approaches using strategic energy planning as a term, clear parallels to the Danish strategic energy planning approach and its challenges do not emerge. It is therefore difficult to identify whether the Danish challenges are general problems. However, Bale et al. have investigated strategic energy planning in the UK [36] and suggest a development of a strategic energy body within local authorities in order to coordinate local energy activities. They find similar challenges for implementing such a body to the ones found in Danish strategic energy planning. Bale et al. highlight four key challenges: financial resources (lack of or inconsistent funding makes it difficult to plan), cultural norms (discomfort with new approaches), skills (lack of technical knowledge and understanding) and political will (depends upon individuals in the city council) [36].

The international literature on strategic energy planning helps to broaden the understanding of how strategic energy planning is used in different situations and several key elements are identified that could be included in the Danish definition of strategic energy planning. However, the literature (except Bale et al. [36]) does not directly show any challenges or provide information that can be helpful in relation to eliminating the identified challenges in the Danish strategic energy planning. Strategic energy planning seems to be a concept that is mentioned in the academic literature with a presupposed assumption of the meaning of the concept. This study indicates that there a several understandings of strategic energy planning in terms of how energy systems are defined, the degree of stakeholder involvement and the institutional level where it is conducted, to mention a few.

Two concrete definitions of strategic energy planning have been identified in this paper. The Danish definition is very technically oriented, whereas the definition from the UN is more concerned with softer aspects, such as environmental and social aspects. However, based on the literature study it seems that the general understanding of strategic energy planning has a primary focus on the technical

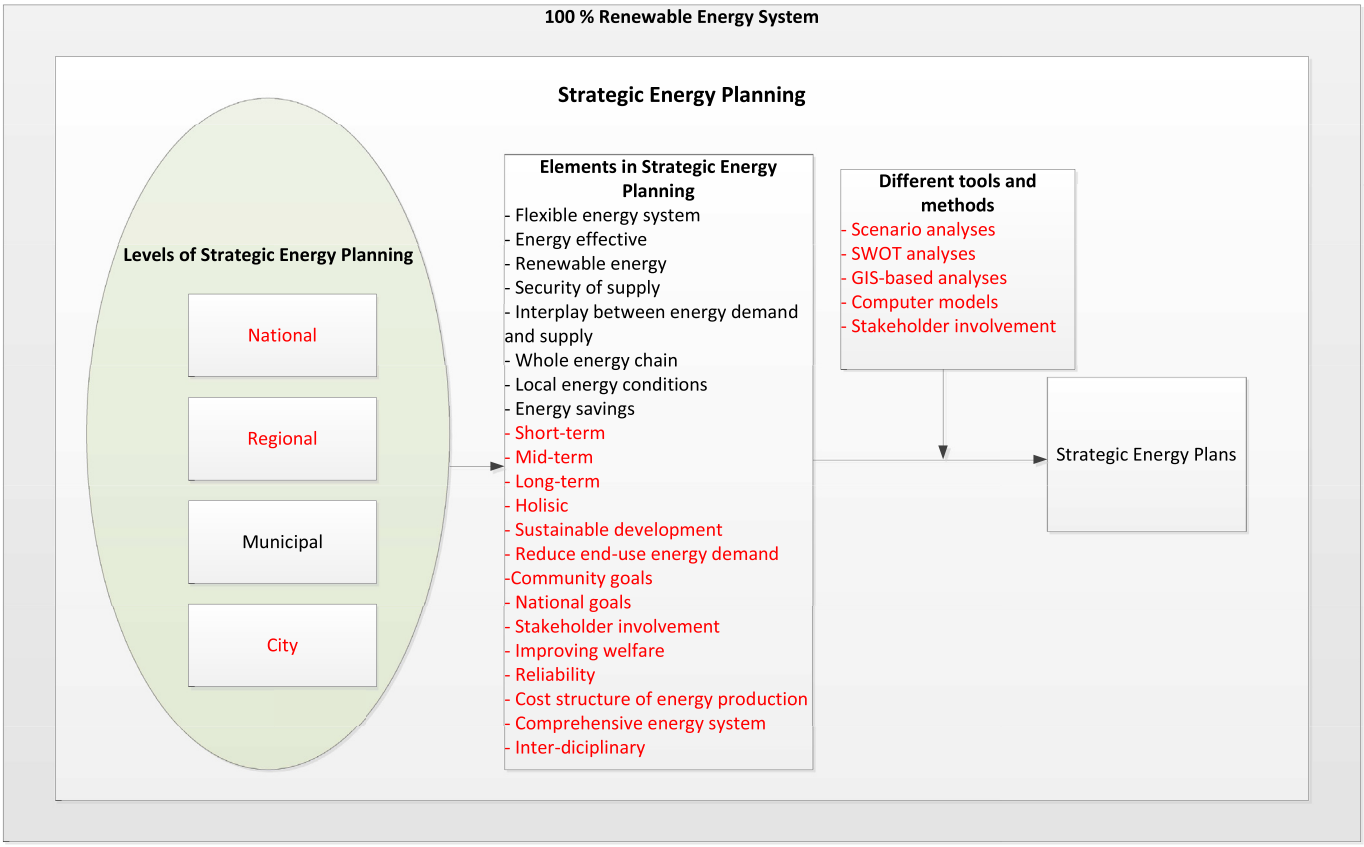

Fig. 3. Dimensions of strategic energy planning. The figure is a development of Fig. 1 based on the knowledge obtained from the international academic literature on strategic energy planning. The figure includes the different institutional levels where strategic energy planning is conducted, an updated list of keywords that can be included in strategic energy plans, a list of identified methods used in relation to the development of strategic energy plans. The red text shows what is new compared to the Danish approach in Fig. 1.

development of strategic energy plans. Furthermore, strategic energy planning is conducted on a national, regional or municipal/local level, though generally only one of the levels is mentioned at a time and the link between the different levels is missing. The Danish and general approach and use of strategic energy planning seem to be narrow and bound to the technical development of strategic energy plans.

Only a few keywords referring to more social elements, such as community goals, improving welfare and stakeholder involvement are identified. Social aspects are difficult to handle and this can be the reason for the gap in the literature, but should not be overlooked in energy planning [84]. Hirsh and Jones [84] showed the importance of not only looking forward when working with energy policies; they argued that history is a crucial part of developing successful energy policies and planning. Considering the historical development of energy systems can give energy planners a better understanding of the non-technical aspects of the energy transition, leading to a better understanding of when and how acceptance of the changes can be achieved.

Based on the findings in the literature reviewed in this paper, we find that the international literature review on strategic energy planning provides inspiration and knowledge, which can help address the challenges found in Danish strategic energy planning today. Danish strategic energy planning is currently understood in a narrow sense and limited to a technical focus at the municipality level, and there is a need for a broader and more inclusive strategic energy planning approach in Denmark. Based on the study in this paper, a theoretical framework for a coherent analysis of strategic energy planning in practice is developed in Fig. 4. As mentioned in the introduction, smart energy systems can be seen as an overall goal for the Danish energy system in the strategic energy planning approach. It would be interesting to investigate if and how the smart energy system concept can be adapted to other contexts. However, within the scope of this paper we choose to add the broader goal of a 100% renewable energy system in the surrounding box in Fig. 4, as such a goal encompasses smart energy systems and other possible energy system configurations.

The main findings that are missing or could be improved in the Danish definition of the strategic energy planning approach are sustainability, focus on societal and social aspects, strategic energy planning on and between different levels and focus on local implementation.

Like most planning processes, strategic energy planning should be considered a dynamic process with many iterations that go far beyond the first strategic energy plan. Long-term energy planning has to deal with uncertain and changing conditions, including technological development and varying societal needs. Therefore, it is important to acknowledge that new knowledge will provide a feedback mechanism in the model, so adjustments can be made along the way to ensure that the most optimal energy solutions are implemented. This is illustrated in Fig. 4, where both new knowledge from the energy plans and experiences from the implementation process provide feedback to the levels of strategic energy planning.

The fact that the definitions of strategic energy planning and the literature only focus on single levels can be inadequate if the national energy policy goals should be reached in the most optimal way, as this can lead to unutilised synergies and increase the risk of sub-optimisation. Communication and coordination between the levels will help to ensure that stakeholders acting in the different levels are working towards a common goal and not working against each other. The benefits of conducting strategic energy planning on different levels in a coordinated way is the flexibility to shape the goals and actions in a way that meet the needs of local societies while still working towards the

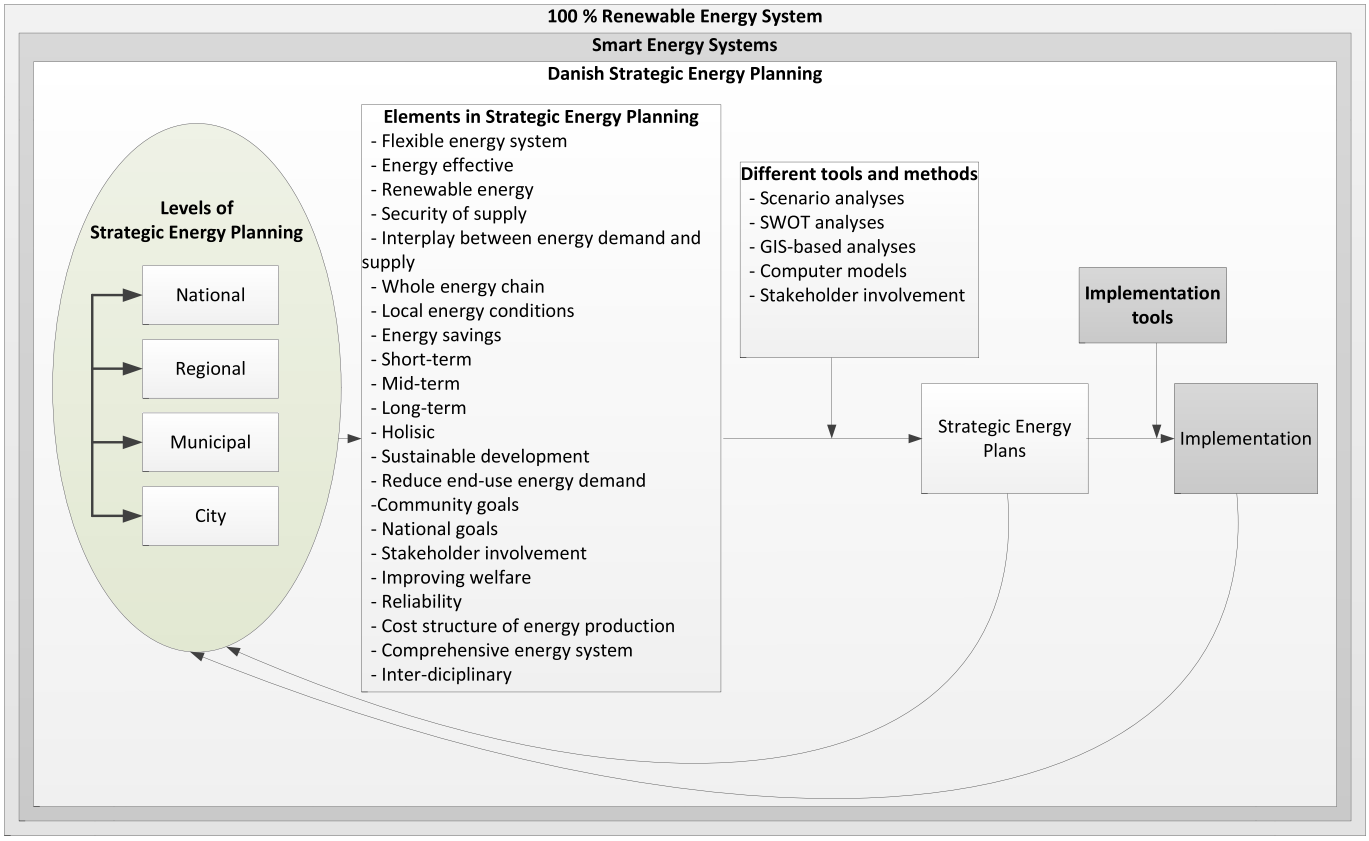

Fig. 4. Theoretical framework of strategic energy planning. A theoretical framework that can be used as an analytical framework when analysing strategic energy planning with a point of departure in the Danish context. The figure illustrates that strategic energy planning should not be limited to only one institutional level; instead research and analysis should focus on the interaction between all institutional levels. The box "Elements in strategic energy planning" provides a list of keywords that can be included in the planning process and plans. This should not be seen as a definite list or as keywords that are required in every single strategic energy plan. However, to reach a 100% renewable energy system, the smart energy system approach is used as the system design. To do this it is necessary to include as many as possible of the keywords in the strategic energy planning process. The different tools and methods used to develop the strategic energy plans should also be selected and used based on the needs in the specific case. Furthermore, two boxes regarding implementation tools and implementation are added in the figure. These are important if the strategic energy plans should actually lead to concrete results and visible projects.

overall national goals. Two grey boxes are added to the figure for implementation tools and implementation. This is done in order to illustrate the inclusion of the complete process in the strategic energy planning approach. Implementation tools can include many different things, such as tools for public participation, subsidy schemes for local developers, different ownership models, etc. However, this is not investigated further in this paper and is therefore not elaborated further in the model. But this is an area in the strategic energy planning that should be researched further.

If strategic energy planning should be used successfully in the Danish energy planning context, it will be essential to look into how the identified narrow approach seen in the strategic energy planning today (Fig. 1) can be transformed into a broader approach that embraces the complete process. This study provides a theoretical framework for analysing the strategic energy planning practices, but to really understand which initiatives must be taken, it is important to examine further how strategic energy planning is conducted in practice in the Danish municipalities as well as nationally and internationally.

6. Conclusion

Strategic energy planning is the planning approach suggested by the Danish government for energy planning in Danish municipalities. To answer the problem statement in this paper "**How can the implementation of strategic energy planning be successfully improved?**", two subjects are investigated. Firstly, knowledge of challenges found in the Danish strategic energy planning are investigated and secondly, how international academic literature on strategic energy planning can shed more light on Danish and other challenges in relation to strategic energy planning is also explored. The methodology of a literature review has been chosen for this study. The literature review of academic papers within strategic energy planning has contributed to expanding the Danish strategic energy planning concept into a more holistic theoretical framework for analysing and practising strategic energy planning.

The analysis shows that the term strategic energy planning is used in relation to many different types of analyses and planning approaches and on different geographical and political levels. We could not find one universally used definition, and in many instances the concept is used without giving a clear definition. In the two definitions of strategic energy planning presented in this study, significant differences are seen between the Danish definition and the UN's definition. Furthermore, many different aspects or keywords are related to the concept in different studies. Today there is a large focus on the technological aspects of the energy system in strategic energy planning and there is a missing link to the more societal aspects in the implementation of the different technologies. In order to tackle the Danish challenges and improve the implementation of strategic energy planning and to synthesise the international terminology, the study presents a new, more holistic theoretical framework for strategic energy planning. We have identified the development of such a framework as a necessary intermediate step in the work with strategic energy planning in Denmark, but also for the

general future research in strategic energy planning concepts and practice.

A suggestion for further research based on this paper is, based on the developed framework, an investigation into the way strategic energy planning is conducted in practice in the Danish municipalities and internationally today. This in order to test and improve the theoretical framework. It would also be beneficial to investigate the existing implementation strategies and tools to identify those that are missing in the strategic energy planning for the strategic energy plans to be successfully implemented. Furthermore, is it important that researches start to more consciously relate to the concept of strategic energy planning when using it in academic literature.

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References

[1] R.B. Hiremath, S. Shikha, N.H. Ravindranath, “Decentralized energy planning; modeling and application—a review, Renew. Sustain. Energy Rev. 11 (5) (2007) 729–752.
[2] A. Mirakyan, R. De Guio, Integrated energy planning in cities and territories: a review of methods and tools, Renew. Sustain. Energy Rev. 22 (2013) 289–297.
[3] Z. Huang, H. Yu, Z. Peng, M. Zhao, Methods and tools for community energy planning: a review, Renew. Sustain. Energy Rev. 42 (2015) 1335–1348.
[4] N. Bagheri Moghaddam, M. Nasiri, S.M. Mousavi, An appropriate multiple criteria decision making method for solving electricity planning problems, addressing sustainability issue, Int. J. Environ. Sci. Tech 8 (3) (2011) 605–620.
[5] K. Sperling, F. Hvelplund, B.V. Mathiesen, Centralisation and decentralisation in strategic municipal energy planning in Denmark, Energy Policy 39 (3) (Mar. 2011) 1338–1351.
[6] T. Damsø, T. Kjær, T.B. Christensen, Local climate action plans in climate change mitigation – examining the case of Denmark, Energy Policy 89 (2016) 74–83.
[7] Energistyrelsen, Strategisk Energiplanlægning I Kommunerne: Kortlægning Og Datafangst - Vejledning I Kortlægningsmetoder Og Datafangst, (2016).
[8] Energistyrelsen, Energiscenarier Frem Mod 2020, 2035 Og 2050, (2014).
[9] Regeringen, VORES ENERGI, (2011).
[10] T. van der Schoor, B. Scholtens, Power to the people: local community initiatives and the transition to sustainable energy, Renew. Sustain. Energy Rev. 43 (2015) 666–675.
[11] B.V. Mathiesen, H. Lund, D. Connolly, H. Wenzel, P.A. Østergaard, B. Möller, S. Nielsen, I. Ridjan, P. Karnøe, K. Sperling, F.K. Hvelplund, Smart Energy Systems for coherent 100% renewable energy and transport solutions, Appl. Energy 145 (2015) 139–154.
[12] Hjørring Kommune, Bæredygtig Energi - Vejen Til Grøn Vækst, (2012).
[13] Energibyen Skive Kommune, Klima Og Energi Strategi 2029, (2016).
[14] Kolding Kommune, Strategisk Energiplan for Kolding Kommune, (2014).
[15] H. Lund, N. Duic, P.A. Østergaard, B.V. Mathiesen, Smart energy systems and 4th generation district heating, Energy 110 (2016) 1–4.
[16] H. Lund, P.A. Østergaard, D. Connolly, B. Vad Mathiesen, Smart energy and smart energy systems, Energy 137 (2017) 556–565.
[17] H. Lund, H. Lund, F. Hvelplund, P. Østergaard, B. Möller, B.V. Mathiesen, D. Connolly, A.N. Andersen, Chapter 6 – Analysis: Smart Energy Systems and Infrastructures, Renewable Energy Systems, 2014, pp. 131–184.
[18] H. Lund, Renewable Energy Systems : a Smart Energy Systems Approach to the Choice and Modeling of 100% Renewable Solutions.
[19] Energikommissionen, Energikommissionens Anbefalinger Til Fremtidens Energipolitik, (2017).
[20] J.Z. Thellufsen, H. Lund, Roles of local and national energy systems in the integration of renewable energy, Appl. Energy 183 (2016) 419–429.
[21] R.D. Prasad, R.C. Bansal, A. Raturi, Multi-faceted energy planning: a review, Renew. Sustain. Energy Rev. 38 (2014) 686–699.
[22] F. Hvelplund, S. Djørup, Multilevel policies for radical transition: governance for a 100% renewable energy system, Environ. Plan. C Polit. Sp. 35 (7) (2017) 1218–1241.
[23] Energistyrelsen, 450 MW Kystnære Havmøller - Nyt Dansk Udbud, (2013).
[24] Energistyrelsen, Oplæg om strategisk energiplanlægning, [Online]. Available: http://www.kl.dk/ImageVaultFiles/id_41857/cf_202/Opl-g_om_strategisk_energiplanl-gning.PDF.
[25] B.V. Mathiesen, H. Lund, K. Hansen, I. Ridjan, S. Djørup, S. Nielsen, P. Sorknæs, J.Z. Thellufsen, L. Grundahl, R. Lund, D. Drysdale, D. Connolly, P.A. Østergaard, IDA's Energy Vision 2050 - a Smart Energy System Strategy for 100 % Renewable Denmark, (2015).
[26] S. Paardekooper, R. Lund, H. Lund, Smart energy systems, in: R.E. Hester, R.M. Harrison (Eds.), Energy Storage OPtions and Their Environmental Impact, the Royal Society of Chemistry, 2018, pp. 228–260.
[27] Folketinget, Energiaftalen Af 22. Marts 2012, (2012) [Online]. Available: http://efkm.dk/media/8031/energiaftale2020.pdf.
[28] D. Sveinbjörnsson, S. Ben Amer-Allam, A.B. Hansen, L. Algren, A.S. Pedersen, Energy supply modelling of a low-CO2 emitting energy system: case study of a Danish municipality, Appl. Energy 195 (2017) 922–941.
[29] J.V. Hoff, B.W. Strobel, A municipal ‘ climate revolution ’? The shaping of municipal climate change policies, J. Transdiscipl. Environ. Stud. 12 (1) (2013) 4–16.
[30] Energistyrelsen, Strategisk Energiplanlægning I Kommunerne: Metodebeskrivelse - Vejledning I Kortlaegningsmetoder Og Datafangst, (2016) [Online]. Available: https://ens.dk/sites/ens.dk/files/Varme/metodebeskrivelse_280916.pdf , Accessed date: 8 March 2017.
[31] Energistyrelsen, Strategisk Energiplanlægning I Kommunerne - Vejledning I Analyser Af Systemændringer Og Scenarieanalyser, (2013) [Online]. Available: https://ens.dk/sites/ens.dk/files/Varme/system_og_scenarieanalyse_vejledning_081013.pdf.
[32] Erhvers- og Vækstministeriet, Planloven - Bekendtgørelse Af Lov Om Planlægning - retsinformation.Dk, (2015) [Online]. Available: https://www.retsinformation.dk/forms/r0710.aspx?id=176182 , Accessed date: 2 June 2016.
[33] Energistyrelsen, Strategisk Energiplanlægning I Kommunerne - Vejledning I Kortlægning Og Datafangst, (2012) [Online]. Available: http://www.ea-energianalyse.dk/reports/1154_vejledning_i_kortlaegningsmetoder_til_strategisk_energiplanlaegning_metodebeskrivelse.pdf.
[34] M.M. Betsill, M.M. Betsill, Mitigating climate change in US cities: opportunities and obstacles, Local Environ. 6 (4) (2001) 393–406.
[35] S. Gustafsson, J. Ivner, J. Palm, Management and stakeholder participation in local strategic energy planning – examples from Sweden, J. Clean. Prod. 98 (2015) 205–212.
[36] C.S.E. Bale, T.J. Foxon, M.J. Hannon, W.F. Gale, Strategic energy planning within local authorities in the UK: a study of the city of Leeds, Energy Policy 48 (2012) 242–251.
[37] V.M.S. Leal, I. Azevedo, Setting targets for local energy planning: critical assessment and a new approach, Sustain. Cities Soc. 26 (2016) 421–428.
[38] United Nations Division for Sustainable Development, Agenda 21 - United Nations Conference on Environment & Development Rio de Janerio, Brazil, 3 to 14 June 1992, (1992).
[39] W. Häfele, IIASA’S world regional energy modelling, Futures 12 (1) (1980) 18–34.
[40] A. Chittum, P.A. Østergaard, How Danish communal heat planning empowers municipalities and benefits individual consumers, Energy Policy 74 (C) (Nov. 2014) 465–474.
[41] S.N. Petrovic, K.B. Karlsson, Danish heat atlas as a support tool for energy system models, Energy Convers. Manag. 87 (2014) 1063–1076.
[42] K. Sperling, How does a pioneer community energy project succeed in practice? The case of the Samsø Renewable Energy Island, Renew. Sustain. Energy Rev. 71 (2017) 884–897.
[43] K. Sperling, B. Möller, End-use energy savings and district heating expansion in a local renewable energy system – a short-term perspective, Appl. Energy 92 (2012) 831–842.
[44] T. Atwood, W. Merritt, J. Kalloz, Strategic Planning for Energy and the Environment Baltimore: Strategic Energy Planning in Charm City, (2017).
[45] A. Poullikkas, I. Hadjipaschalis, G. Kourtis, The cost of integration of parabolic trough CSP plants in isolated Mediterranean power systems, Renew. Sustain. Energy Rev. 14 (5) (2010) 1469–1476.
[46] A. De Montis, Strategic environmental assessment of energy planning tools. A study of Italian regions and provinces, Environ. Impact Assess. Rev. 46 (2014) 32–42.
[47] R.E. Bush, C.S.E. Bale, P.G. Taylor, Realising local government visions for developing district heating: experiences from a learning country, Energy Policy 98 (2016) 84–96.
[48] D. Brookshire, N. Kaza, Planning for seven generations: energy planning of American Indian tribes, Energy Policy 62 (2013) 1506–1514.
[49] Q. Zhang, T. Tezuka, K.N. Ishihara, B.C. Mclellan, Integration of PV power into future low-carbon smart electricity systems with EV and HP in Kansai Area, Japan, Renew. Energy 44 (2012) 99–108.
[50] Y. Zhou, C. Rengifo, P. Chen, J. Hinze, Is China ready for its nuclear expansion? Energy Policy 39 (2) (2011) 771–781.
[51] W. Alonso-Pippo, C.A. Luengo, L. Alonsoamador Morales Alberteris, G. García del Pino, S. Duvoisin, Practical implementation of liquid biofuels: the transferability of the Brazilian experiences, Energy Policy 60 (2013) 70–80.
[52] O.H. Anuta, P. Taylor, D. Jones, T. McEntee, N. Wade, An international review of the implications of regulatory and electricity market structures on the emergence of grid scale electricity storage, Renew. Sustain. Energy Rev. 38 (2014) 489–508.
[53] N. Behling, M.C. Williams, S. Managi, Fuel cells and the hydrogen revolution: analysis of a strategic plan in Japan, Econ. Anal. Policy 48 (2015) 204–221.
[54] J.D. Bricker, M. Esteban, H. Takagi, V. Roeber, Economic feasibility of tidal stream and wave power in post-Fukushima Japan, Renew. Energy 114 (2017) 32–45.
[55] S. Kang, S. Selosse, N. Maïzi, Strategy of bioenergy development in the largest energy consumers of Asia (China, India, Japan and South Korea), Energy Strateg. Rev. 8 (2015) 56–65.
[56] A. Shogenova, S. Šliaupa, K. Shogenov, R. Šliaupiene, R. Pomeranceva, R. Vaher, M. Uibu, R. Kuusik, Possibilities for geological storage and mineral trapping of industrial CO2 emissions in the Baltic region, Energy Procedia 1 (1) (2009) 2753–2760.
[57] V. Vivoda, Natural gas in Asia: trade, markets and regional institutions, Energy Policy 74 (2014) 80–90.
[58] E. Kiriyama, Y. Kajikawa, K. Fujita, S. Iwata, A lead for transvaluation of global nuclear energy research and funded projects in Japan, Appl. Energy 109 (2013) 145–153.
[59] R. Komiyama, Y. Fujii, Assessment of post-Fukushima renewable energy policy in Japan's nation-wide power grid, Energy Policy 101 (2017) 594–611.
[60] D.N. Mah, Y.-Y. Wu, J.C. Ip, P.R. Hills, The role of the state in sustainable energy transitions: a case study of large smart grid demonstration projects in Japan, Energy Policy 63 (2013) 726–737.
[61] B. Müller, The case for Japanese–Russian joint implementation in implementing

the Kyoto Protocol, Clim. Policy 1 (3) (2001) 403–410.
[62] S. Ohnishi, M. Fujii, M. Ohata, I. Rokuta, T. Fujita, Efficient energy recovery through a combination of waste-to-energy systems for a low-carbon city, Resour. Conserv. Recycl. 128 (January 2018) 394–405.
[63] K. Oshiro, T. Masui, Diffusion of low emission vehicles and their impact on CO2 emission reduction in Japan, Energy Policy 81 (2015) 215–225.
[64] A. Ozawa, R. Furusato, Y. Yoshida, Determining the relationship between a household's lifestyle and its electricity consumption in Japan by analyzing measured electric load profiles, Energy Build. 119 (2016) 200–210.
[65] M. Papa, N.W. Gleason, Major emerging powers in sustainable development diplomacy: assessing their leadership potential, Glob. Environ. Chang. 22 (4) (2012) 915–924.
[66] W. Poortinga, M. Aoyagi, N.F. Pidgeon, Public perceptions of climate change and energy futures before and after the Fukushima accident: a comparison between Britain and Japan, Energy Policy 62 (2013) 1204–1211.
[67] J. Portugal Pereira, G. Troncoso Parady, B. Castro Dominguez, Japan's energy conundrum: post-Fukushima scenarios from a life cycle perspective, Energy Policy 67 (2014) 104–115.
[68] J. Portugal-Pereira, M. Esteban, Implications of paradigm shift in Japan's electricity security of supply: a multi-dimensional indicator assessment, Appl. Energy 123 (2014) 424–434.
[69] X. Su, W. Zhou, F. Sun, K. Nakagami, Possible pathways for dealing with Japan's post-Fukushima challenge and achieving CO2 emission reduction targets in 2030, Energy 66 (2014) 90–97.
[70] S. Suzuki, T. Nakamura, M. Muraoka, S. Higashi, T. Ohsumi, Regulations on ship transport and on-board direct injection of CO2 into sub-seabed geological formations, Energy Procedia 37 (2013) 3191–3198.
[71] Y. Tanaka, M. Abe, Y. Sawada, D. Tanase, T. Ito, T. Kasukawa, Tomakomai CCS demonstration project in Japan, 2014 update, Energy Procedia 63 (2014) 6111–6119.
[72] D. Tomofuji, Y. Morimoto, E. Sugiura, T. Ishii, A. Akisawa, The prospects of the expanded diffusion of cogeneration to 2030 – study on new value in cogeneration, Appl. Therm. Eng. 114 (2017) 1403–1413.
[73] M.L. Tuballa, M.L. Abundo, A review of the development of Smart Grid technologies, Renew. Sustain. Energy Rev. 59 (2016) 710–725.
[74] S.V. Valentine, Japanese wind energy development policy: grand plan or group think? Energy Policy 39 (11) (2011) 6842–6854.
[75] N. Yabe, Environmental and economic evaluations of centralized biogas plants running on cow manure in Hokkaido, Japan, Biomass Bioenergy 49 (2013) 143–151.
[76] Q. Zhang, K.N. Ishihara, B.C. Mclellan, T. Tezuka, Scenario analysis on future electricity supply and demand in Japan, Energy 38 (1) (2012) 376–385.
[77] Q. Zhang, B.C. Mclellan, T. Tezuka, K.N. Ishihara, Economic and environmental analysis of power generation expansion in Japan considering Fukushima nuclear accident using a multi-objective optimization model, Energy 44 (1) (2012) 986–995.
[78] K. Calder, Beyond Fukushima: Japan's emerging energy and environmental challenges, Orbis 57 (3) (2013) 438–452.
[79] J.S. Duffield, B. Woodall, Japan's new basic energy plan, Energy Policy 39 (6) (2011) 3741–3749.
[80] H. Hatayama, K. Tahara, Evaluating the sufficiency of Japan's mineral resource entitlements for supply risk mitigation, Resour. Pol. 44 (2015) 72–80.
[81] M. Hayashi, L. Hughes, The policy responses to the Fukushima nuclear accident and their effect on Japanese energy security, Energy Policy 59 (2013) 86–101.
[82] Y. Ishimoto, A. Kurosawa, M. Sasakura, K. Sakata, Significance of CO2-free hydrogen globally and for Japan using a long-term global energy system analysis, Int. J. Hydrog. Energy 42 (19) (2017) 13357–13367.
[83] E. Kiriyama, Y. Kajikawa, A multilayered analysis of energy security research and the energy supply process, Appl. Energy 123 (2014) 415–423.
[84] R.F. Hirsh, C.F. Jones, History's contributions to energy research and policy, Energy Res. Soc. Sci. 1 (2014) 106–111.
[85] S. Blegaa, L. Josephsen, N.I. Meyer, B. Sørensen, Alternative Danish energy planning, Energy Policy 5 (2) (Jun. 1977) 87–94.
[86] R.S. Adhikari, N. Aste, M. Manfren, Optimization concepts in district energy design and management – a case study, Energy Procedia 14 (2012) 1386–1391.
[87] D. Dijk, M. Kok, A comparison of different modelling approaches to strategic energy planning, Eur. J. Oper. Res. 29 (1) (1987) 42–50.
[88] S.C. Bhattacharyya, S. Ohiare, The Chinese electricity access model for rural electrification: approach, experience and lessons for others, Energy Policy 49 (2012) 676–687.
[89] S. Pfenninger, A. Hawkes, J. Keirstead, Energy systems modeling for twenty-first century energy challenges, Renew. Sustain. Energy Rev. 33 (2014) 74–86.
[90] C. Blumstein, C. Goldman, G. Barbose, Who should administer energy-efficiency programs? Energy Policy 33 (8) (2005) 1053–1067.
[91] J. Terrados, G. Almonacid, P. Pérez-Higueras, Proposal for a combined methodology for renewable energy planning. Application to a Spanish region, Renew. Sustain. Energy Rev. 13 (8) (2009) 2022–2030.
[92] V. Codina Gironès, S. Moret, F. Maréchal, D. Favrat, Strategic energy planning for large-scale energy systems: a modelling framework to aid decision-making, Energy 90 (2015) 173–186.
[93] S. Jay, Strategic environmental assessment for energy production, Energy Policy 38 (7) (2010) 3489–3497.
[94] T.J. Stewart, S. French, J. Rios, Integrating multicriteria decision analysis and scenario planning—review and extension, Omega 41 (4) (2013) 679–688.
[95] C. Ioakimidis, N. Koukouzas, A. Chatzimichali, S. Casimiro, A. Macarulla, Energy policy scenarios of CCS implementation in the Greek electricity sector, Energy Procedia 23 (2012) 354–359.
[96] M.J. Collier, Z. Nedović-Budić, J. Aerts, S. Connop, D. Foley, K. Foley, D. Newport, S. McQuaid, A. Slaev, P. Verburg, Transitioning to resilience and sustainability in urban communities, Cities 32 (2013) S21–S28.
[97] A. Phdungsilp, Futures studies' backcasting method used for strategic sustainable city planning, Futures 43 (7) (2011) 707–714.
[98] C. Morlet, J. Keirstead, A comparative analysis of urban energy governance in four European cities, Energy Policy 61 (2013) 852–863.
[99] S. Cajot, M. Peter, J.-M. Bahu, F. Guignet, A. Koch, F. Maréchal, Obstacles in energy planning at the urban scale, Sustain. Cities Soc. 30 (2017) 223–236.
[100] H. Al Garni, A. Kassem, A. Awasthi, D. Komljenovic, K. Al-Haddad, A multicriteria decision making approach for evaluating renewable power generation sources in Saudi Arabia, Sustain. Energy Technol. Assessments 16 (2016) 137–150.
[101] S. Koskela, J. Seppälä, A. Lipp, M.-R. Hiltunen, E. Põld, S. Talve, Estonian electricity supply scenarios for 2020 and their environmental performance, Energy Policy 35 (7) (2007) 3571–3582.
[102] B. Lin, J. Liu, Y. Yang, Impact of carbon intensity and energy security constraints on China's coal import, Energy Policy 48 (2012) 137–147.
[103] C. Meza, A review on the Central America electrical energy scenario, Renew. Sustain. Energy Rev. 33 (2014) 566–577.
[104] M. Procesi, B. Cantucci, M. Buttinelli, G. Armezzani, F. Quattrocchi, E. Boschi, Strategic use of the underground in an energy mix plan: synergies among CO2, CH4 geological storage and geothermal energy. Latium Region case study (Central Italy), Appl. Energy 110 (2013) 104–131.
[105] P.E. Robins, S.P. Neill, M.J. Lewis, S.L. Ward, Characterising the spatial and temporal variability of the tidal-stream energy resource over the northwest European shelf seas, Appl. Energy 147 (2015) 510–522.
[106] K. Sipilä, C. Wilén, The structure and achievements of the bioenergy network of excellence, Biomass Bioenergy 38 (2012) 2–13.
[107] D. Streimikiene, Comparative assessment of future power generation technologies based on carbon price development, Renew. Sustain. Energy Rev. 14 (4) (2010) 1283–1292.
[108] A. Valente, D. Iribarren, J. Dufour, Harmonised life-cycle global warming impact of renewable hydrogen, J. Clean. Prod. 149 (2017) 762–772.
[109] Niels I. Meyer, Brian Vad Mathiesen, Frede Hvelplund, Barriers and potential solutions for energy renovation of buildings in Denmark, Int. J. Sustain. Energy Plan. Manag. 1 (2014) 59–66.
[110] N. Edomah, C. Foulds, A. Jones, Policy making and energy infrastructure change: a Nigerian case study of energy governance in the electricity sector, Energy Policy 102 (2017) 476–485.
[111] J.-F. Mercure, P. Salas, An assessement of global energy resource economic potentials, Energy 46 (1) (2012) 322–336.
[112] J. Zinck Thellufsen, H. Lund, Cross-border versus cross-sector interconnectivity in renewable energy systems, Energy 124 (2017) 492–501.
[113] M. Procesi, M. Buttinelli, M. Pignone, Geothermal favourability mapping by advanced geospatial overlay analysis: tuscany case study (Italy), Energy 90 (2015) 1377–1387.
[114] Y.-H. Shih, C.-H. Tseng, Cost-benefit analysis of sustainable energy development using life-cycle co-benefits assessment and the system dynamics approach, Appl. Energy 119 (2014) 57–66.
[115] F.O. Rourke, F. Boyle, A. Reynolds, Tidal energy update 2009, Appl. Energy 87 (2) (2010) 398–409.
[116] T.S. Grindsted, Regional planning, sustainability goals and the mitch-match between educational practice and climate, energy and business plans, J. Clean. Prod. 171 (10 January 2018) 1681–1690.
[117] V.A. Stennikov, E.E. Iakimetc, Optimal planning of heat supply systems in urban areas, Energy 110 (2016) 157–165.
[118] J. Williams, The deployment of decentralised energy systems as part of the housing growth programme in the UK, Energy Policy 38 (12) (2010) 7604–7613.
[119] A. Pellizzone, A. Allansdottir, R. De Franco, G. Muttoni, A. Manzella, Geothermal energy and the public: a case study on deliberative citizens' engagement in central Italy, Energy Policy 101 (2017) 561–570.
[120] S. Clark, Scotland gets serious about low carbon heat, Renewable Energy Focus 16 (4) (2015) 62–63.
[121] R. Madlener, Y. Sunak, Impacts of urbanization on urban structures and energy demand: what can we learn for urban energy planning and urbanization management? Sustain. Cities Soc. 1 (1) (2011) 45–53.
[122] R. Thery, P. Zarate, Energy planning: a multi-level and multicriteria decision making structure proposal, CEJOR 17 (2009) 265–274.
[123] C. Cormio, M. Dicorato, A. Minoia, M. Trovato, A regional energy planning methodology including renewable energy sources and environmental constraints, Renew. Sustain. Energy Rev. 7 (2) (2003) 99–130.
[124] S.D. Pohekar, M. Ramachandran, Application of multi-criteria decision making to sustainable energy planning—a review, Renew. Sustain. Energy Rev. 8 (4) (2004) 365–381.
[125] A.R. Neves, V. Leal, Energy sustainability indicators for local energy planning: review of current practices and derivation of a new framework, Renew. Sustain. Energy Rev. 14 (9) (2010) 2723–2735.
[126] N.C. Lee, V.M.S. Leal, A review of energy planning practices of members of the Economic Community of West African States, Renew. Sustain. Energy Rev. 31 (2014) 202–220.
[127] C. Bhowmik, S. Bhowmik, A. Ray, K.M. Pandey, Optimal green energy planning for sustainable development: a review, Renew. Sustain. Energy Rev. 71 (2017) 796–813.
[128] M.B. Blarke, B.M. Jenkins, SuperGrid or SmartGrid: competing strategies for large-scale integration of intermittent renewables? Energy Policy 58 (2013) 381–390.